higher." They demonstrated the technique on a silicon structure with a 8.2 mm long channel, with a 0.1 mm height that was open at both ends. Folta et al. reported that the SiN coating on the exterior of the device was 138 nm thick and a uniform thickness of 115 nm within the channel, with the surfaces of the tapered ports having an intermediate thickness. Folta's technique appears to provide good surface protection for some relatively simple silicon devices; however, the technique appears to have several limitations, including: it is specific to SiN-coated silicon and, for example, does not appear capable of providing a uniform oxide coating; the technique does not appear applicable for applying uniform coatings to complex structures, for example channels with sharp bends; there is no indication of the coating uniformity at microchannel corners; and the technique is shown to result in thicker coatings on exterior surfaces—this could cause flow problems and even occlusions at the inlets/outlets of some microchannel apparatus.

[0015] It is believed that conventional CVD techniques are unlikely to produce uniform coatings within microchannels because thicker coatings would be expected near channel openings and in features such as sharp turns and orifices, and in channel corners. The coatings described above by Folta et al. appear exceptionally uniform for a CVD process, but even in that case there was greater thickness on the device's exterior and in the ports leading to the microchannel.

[0016] Electroless metal coatings have long been known and are reviewed by Mallory et al. eds., "Electroless Plating Fundamentals & Applications," American Electroplaters Society (1990) and Chepuri et al., "Chemical and electrochemical depositions of platinum group metals and their applications," Coord. Chem. Rev., vol. 249, pp. 613-631 (2005). Yekimov et al., in U.S. Pat. No. 6,361,824 reported the electroless coating of silver on microchannels through a very thin glass sheet. The microchannels could be 50 to 1000 microns (μm) in length. It was reported that the microchannels must by horizontally aligned during coating. Yekimov et al. also reported that to avoid clogging, the upper and lower surfaces of the glass plate needed to be unobstructed. Even with limiting the microchannel to these extremely short lengths, the coating of metallic silver was reported to be 30 to 50 nm thick.

[0017] As described below, the present invention provides novel microchannel apparatus having uniform or tailored coatings and novel methods of making these coatings. The invention also includes methods of conducting unit operations through microchannel devices with coated microchannels.

SUMMARY OF THE INVENTION

[0018] In a first aspect, the invention provides microchannel apparatus, comprising: an interior microchannel comprising a microchannel wall; and a contiguous post-assembly coating along a contiguous length of at least 1 cm of the microchannel wall. The contiguous post-assembly coating has a contiguous length of at least 1 cm that has an average thickness (measured perpendicular to the microchannel length and in the direction in which a coating grows away from the wall) of at least 5 μm and wherein at least 90% of the contiguous length of coating is within +/−20% of the average thickness. In every aspect mentioned herein, the at least 1 cm coating lengths can, in some preferred embodiments, be at least 5, at least 20, or at least 50 cm. Likewise, in every aspect mentioned herein, the at least 90% can, in some preferred embodiments, be at least 95%, or 100%. Also, in every aspect mentioned herein, the within +/−20% can, in some preferred embodiments, be within 10% or within 5%. In various embodiments of each aspect, coatings can be at least 5 μm thick, or at least 15 μm thick, or at least 25 μm thick. Also, in place of percent variance, coating thickness variability can be defined in absolute values of ±5 μm or less, or +3 μm or less.

[0019] In some preferred embodiments, the microchannel apparatus is provided with a uniform coating, by CVD of aluminum compounds and formation of an aluminide layer.

[0020] In another aspect, the invention provides a method of applying a washcoat onto a microchannel wall, comprising: providing a microchannel apparatus comprising a microchannel defined by at least one microchannel wall, wherein the at least one microchannel wall comprises capillary features; adding a washcoating liquid to the microchannel and contacting the capillary features; and draining the washcoating liquid from the microchannel. The capillary features do not include a contiguous path over the entire length of the microchannel.

[0021] In a further aspect, the invention provides microchannel apparatus, comprising: an interior, complex microchannel comprising a microchannel wall; and a contiguous post-assembly coating along a contiguous length of at least 1 cm of the microchannel wall. The contiguous post-assembly coating has a contiguous length of at least 1 cm that has an average thickness (measured perpendicular to the microchannel length and in the direction in which a coating grows away from the wall) of at least 1 μm and at least 90% of the contiguous length of coating is within +/−20% of the average or mean thickness.

[0022] In another aspect, the invention provides microchannel apparatus, comprising: an interior microchannel comprising a microchannel wall; and a contiguous post-assembly alumina coating along a contiguous length of at least 1 cm of the microchannel wall. The contiguous post-assembly coating has a contiguous length of at least 1 cm that has an average thickness (measured perpendicular to the microchannel length and in the direction in which a coating grows away from the wall) of at least 1 cm and at least 90% of the contiguous length of coating is within +/−20% of the average thickness.

[0023] In yet another aspect, the invention provides microchannel apparatus, comprising: a plurality of parallel interior microchannels sharing a common manifold; wherein each microchannel comprises a metallic wall; and a contiguous post-assembly coating along a contiguous length of at least 1 cm of the metallic wall of at least 90% of the microchannels in the plurality of microchannels. The contiguous post-assembly coating has a contiguous length of at least 1 cm that has an average thickness (measured perpendicular to the microchannel length and in the direction in which a coating grows away from the wall) of at least 1 μm, and the contiguous post-assembly coating in each of the microchannels in the at least 90% of the microchannels in the plurality of microchannels has a length and coating loading that is within +/−20% of the average length and coating loading for the plurality of parallel interior microchannels sharing a common manifold.